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Extraction and validation of biophysical parameters of grassland communities using field spectroradiometric reflectance measurements

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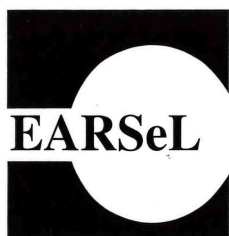
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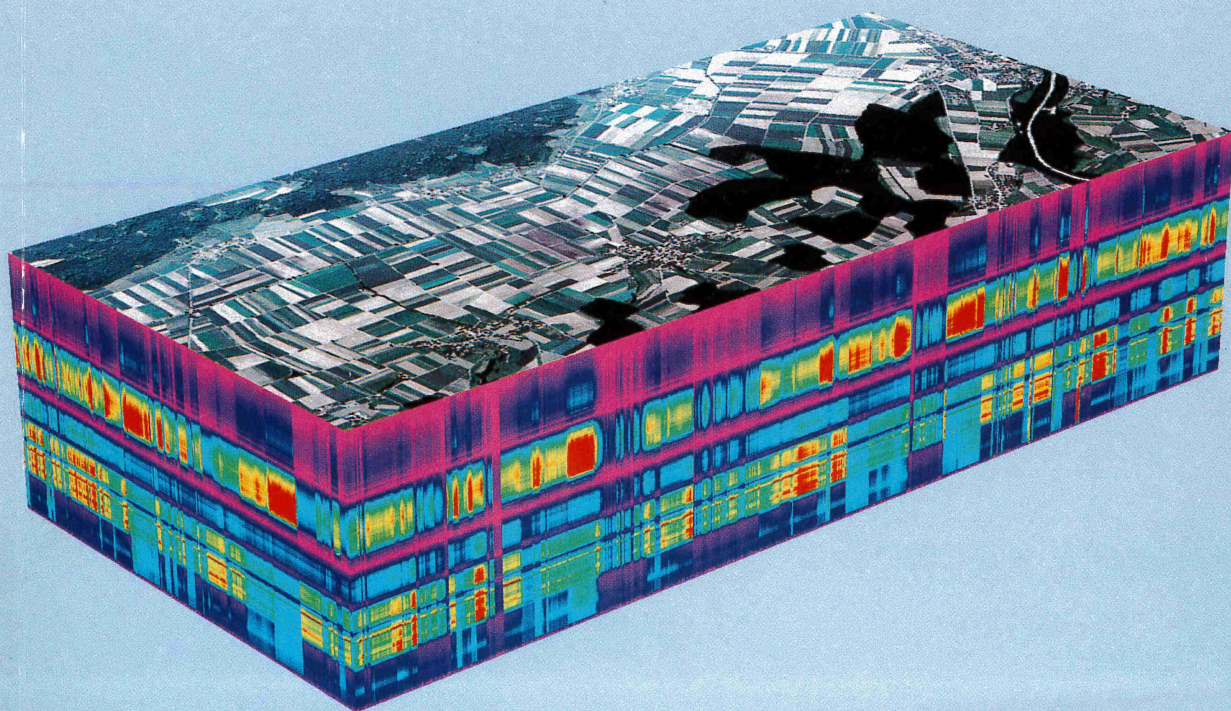
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LABORATORIES



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EXTRACTION AND VALIDATION OF BIOPHYSICAL VARIABLES OF GRASSLAND COMMUNITIES USING FIELD SPECTRORADIOMETRIC MEASUREMENTS

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ABSTRACT

Ground spectroradiometric measurements using a GER3700 spectroradiometer on grassland communities are used to assess the potential of unmixing methods, derivative spectroscopy, and spectral feature fitting. The reference test site used for this work is a well controlled and maintained area by a multinational biodiversity project, namely 'BIODEPTH'. Results of the application of the different methods are discussed in order to retrieve vegetation cover and nitrogen content.

KEYWORDS:

Grassland Communities, Spectral Feature Fitting, Spectral Unmixing, Canopy Nitrogen Content, Vegetation Cover

1 INTRODUCTION

The knowledge about the biochemical composition and the structure of vegetation allows to model the primary productivity as well as the description of the nutrient cycles of the ecosystems. Nitrogen content influences the photosynthetic activity, LAI (Leaf Area Index) and vegetation cover define the space filling by plants—they are related to the microclimate (e.g. evapotranspiration), and to processes like soil erosion and weed invasion. The objective of this paper is to evaluate the potential of spectroradiometric measurements in the determination of these parameters.

The data acquisition took place on the test site of the BIODEPTH-project [5] (Biodiversity and Ecological Processes in Terrestrial Herbaceous Ecosystems: Experimental Manipulations of Plant Communities). Diversity levels of the 64 artificially established grassland fields of 2 x 8m reached from monoculture to a maximum variety of species of 32. The analysis of this project specific dataset using diverse long-term measurement periods will answer to following questions [5]:

- Does a high diversity in plant species increase the ecosystem resilience, stress tolerance and invasion resistance?
- Do different species, ecotypes or genotypes show differential responses to declining diversity?
- How are ecosystem processes and the population dynamics of target species influenced by biodiversity and how is this effect modified by environmental heterogeneity?

- What is the impact of various functional groups and their presence on ecosystem functioning?

One of eight testsites of the BIODEPTH project has been established in 1995 at Lupsingen, located in the Swiss Jura mountains. Amongst other measurements, the determination of the vegetation cover, LAI (using a LAI2000 meter from Li-COR), biomass and nitrogen content are part of the long-term measurements.

Spectroradiometric data acquisition is based on stratified random sampling on all of the 64 plots of the testsite. During the growing season in 1997 (June to September) six field campaigns have been carried out resulting in about 200 reflectance spectra representing different species, diversity levels and phenological states. Field reflectance measurements are performed using a nadir looking GER3700 spectroradiometer (spectral range: 400-2500nm) at 2m above ground. To minimize the influence of atmospheric effects, each target measurement is divided by a reference measurement (Spectralon panel) taken before each single measurement. Regions influenced by atmospheric water vapour are not considered for later data analysis and removed from the original data.

2 METHODOLOGIES

2.1 Vegetation cover

The exact knowledge about vegetation cover is important for ecologists in order to evaluate processes such as erosion dynamics and evapotranspiration. It defines the two-dimensional ground coverage whereas the LAI describes the three-dimensional space filling. Reflectance spectra of vegetation canopies consist of plant as well as bare ground signal. If the influence of soil effects on vegetation spectra can be quantified, conclusions on vegetation cover can be derived. In a first step it is evaluated whether there is a potential to determine vegetation cover using reflectance spectra.

Although there is no evidence for a linear behaviour of radiance processes in vegetation canopies, linear spectral unmixing is used in a first approach to determine abundances of soil and vegetation signal in a mixed spectrum. In this study, the endmember selection is based on the following measurements: a vegetation spectra of the reference testsite with a 100% coverage and the measurement of a bare soil just nearby the plots. The effect of litter and shade present in the vegetation spectrum is not quantified, because no significant endmember was available. This may introduce a significant error, because the litter coverage varies between 0 and 45%.

The linear spectral unmixing algorithm used is implemented in ENVI [9] and here the unconstrained option is applied over the whole spectral range. The results obtained represent subsequently the abundances of these two endmembers in the pixels measured at different points in time. The quality of these results is verified by comparing the abundances with vegetation cover data collected in field campaigns in the framework of BIODEPTH-project. The uncertainty introduced whilst not all vegetation cover data are collected at the same day as the reflectance spectra (Table 1) may be large. In addition, the correlation of the LAI measurements and vegetation cover data do not show a linear relation (Figure 1).

TABLE 1. Comparison of data acquisition of reflectance measurements and BIODEPTH attribute data.

Parameter	Data acquisition	
	August	September
Reflectance Measurement	13. & 16.8.97	5.9.97
Vegetation cover	18.-22.8.97	2.9.97
LAI	27.8.97	12.9.97

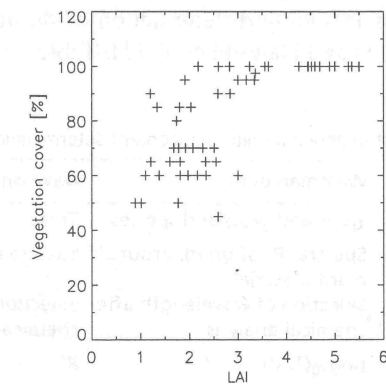


FIGURE 1: Relation of LAI and vegetation cover.

2.2 Nitrogen content

Photosynthetic activity shows a high dependence on nitrogen content of plants, which ranges from 2 to 4% in leaves of grassland species. Lack of nitrogen results in plants becoming stunted and subsequently reproduction processes and senescence occur prematurely [8]. The determination of nitrogen content in laboratories is tedious and time consuming. Data collection by means of remote sensing would be easier and give the possibility to control larger areas in shorter time.

Investigations on nitrogen content derived from spectral analysis seem to be successful if spectra of dried and ground plant material are analysed [11]. Because of the leaf water content and therefore the more complex radiation processes, the determination of nitrogen content using the spectral signatures of vegetation canopies remains difficult. An approach could be to remove the effect of soil, and then the significant absorption features, shifted and often covered by leaf water effects, may be located.

To avoid correlation errors, the spectral position of these absorption features is extracted from the literature [3][7][11] and used to analyse the reflectance spectra. The elimination of the soil signal is performed using two different methods: a) differentiation of the reflectance spectra in order to reduce the influence of a linear background signal [4], and b) spectral feature fitting including a spectral normalization which removes the continuum representing background effects [1].

The data analysis including differentiation of the reflectance spectra is carried out following Wessman et al. [11] and Dawson et al. [3]. Table 2 shows a comparison of their methods and results.

TABLE 2. Comparison of methods for nitrogen content determination by Wessman and Dawson.

	Wessman et al.	Dawson et al.
Investigated vegetation	Trees and grassland species	Trees
Dataset	Spectra (R) of dried, ground plant material Selection of wavelength after chemical analysis	Spectra of AVIRIS (R [%]) Selection of wavelength after chemical analysis
Data transformation	$(\log_{10}(1/R))'$	R'
Wavelength [nm]	2053 2063 2129 2181 2293	1188 1230 1690 2168 2294
Resulting correlation	$r^2 = 0.98$	$r^2 = 0.85$

Analysis by spectral feature fitting is based on single absorption features of a biochemical parameter itself or even plant components (e.g. chlorophyll concentration) related to it. A region around an absorption band is normalized and compared to a spectral feature with a specific depth for a certain concentration of nitrogen content. The following spectral regions are investigated to determine nitrogen content (Table 3):

TABLE 3. List of spectral regions applied for spectral feature fitting.

absorbing component	referenced wave-length region [nm]	applied wavelength region [nm]
Chlorophyll a and b	640-675 [10], [12]	544-770
Protein, nitrogen	1510, 1520 [6]	1537-1587
Protein, nitrogen	1690 [2]	1622-1639

After the continuum removal, a reference spectra of vegetation with minimal (1.75%) and maximal nitrogen content (3.96%) determined by the CHN-analysis is selected (Figure 2). The result of the feature fitting is a scale factor indicating the depth of the absorption feature in relation to the reference spectrum. A scale factor of one means that the absorption band of the investigated spectrum has the same depth as the reference spectrum.

Multiplication of the scale factor with nitrogen content represented by the reference spectrum leads to nitrogen content of the investigated vegetation canopy.

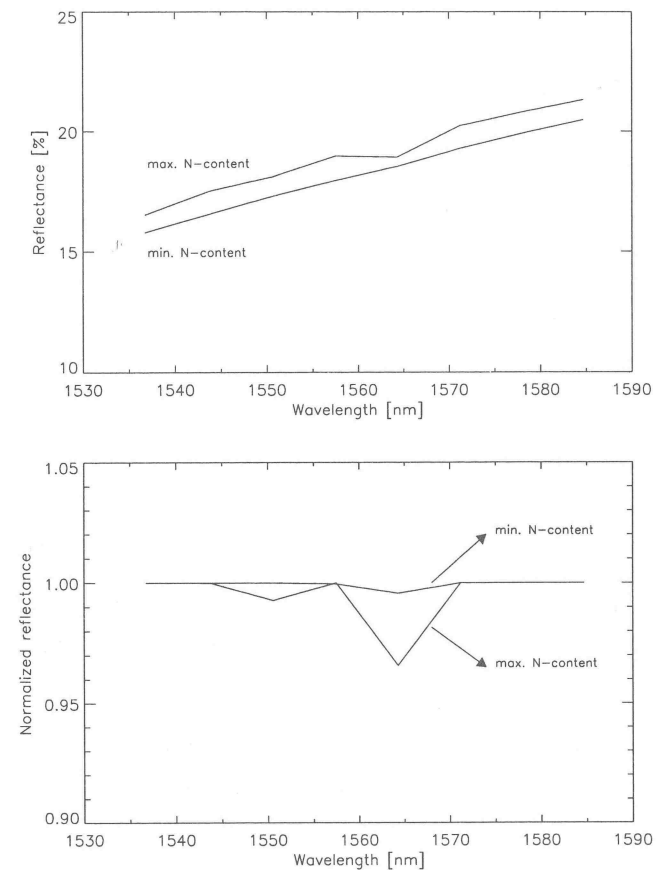


FIGURE 2: Selected reference spectra in the region of 1537-1585nm are shown (top). Continuum removal leads to normalized spectra with values of zero to one. The spectrum of vegetation canopy with maximal nitrogen content shows a deeper absorption band (bottom).

3 RESULTS AND DISCUSSION

3.1 Vegetation cover determination

A strong linear relation between linear unmixing results and the verification dataset of vegetation cover can be found for the data of August (Figure 3). The September data show lower correspondence (Figure 3).

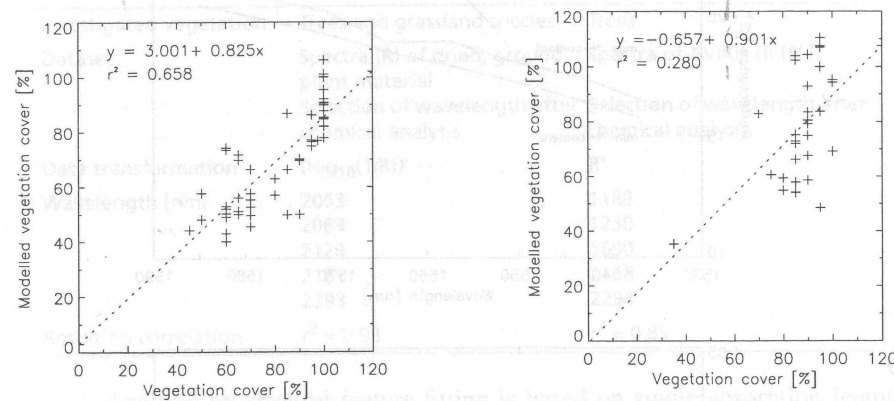


FIGURE 3: Regression between vegetation abundances, and reference data. The data is collected in August (left) and September (right).

The following reasons can explain some of the deviation:

- Vegetation cover in September shows a low gradient; most of the 32 measured fields have a cover between 70 to 100%.
- Vegetation cover in the reference data include litter. Since the dead plant material does not contain chlorophyll, the linear unmixing procedure assumes litter to be soil.
- Unmixing is based on a linear algorithm. Radiance processes in vegetation canopies may not be considered as linear.
- The quality of the results is represented by the RMS (Root Mean Square) which shows the deviation of the sum of the abundances from one. The average of the RMS is located around 10% of the reflectance and can only be reduced by selecting endmembers by a mathematical approach (e.g. Pixel Purity Index).

The comparison of unmixing results with the LAI verification data leads to slightly higher r^2 values (Figure 4). This is an evidence that the applied method is a reliable way to determine parameters such as vegetation cover and LAI.

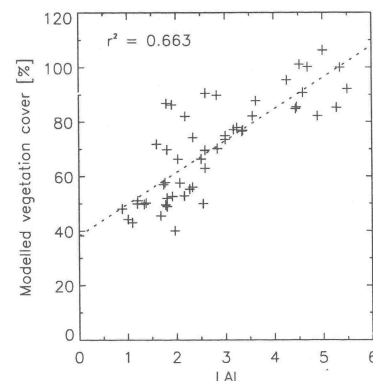


FIGURE 4: Regression of unmixing results and LAI reference data of August 1997.

3.2 Nitrogen content

The results of derivative spectroscopy do not show the expected linear correlation with the reference data (Figure 5). Variations of real nitrogen content ranging from 2 to 4% are represented by modelled values of 2.7 to 3.3%. The selected wavelengths are not significant for nitrogen content of the investigated dataset. Although better results in the analysis following Dawson et al. [3] are expected, the spectral transformation and wavelengths proposed by Wessman et al. [11] for dried plant material lead to a slightly better correlation (Figure 5).

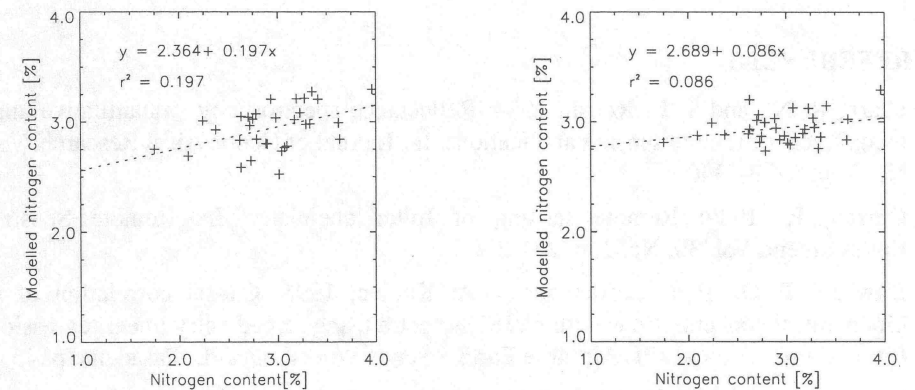


FIGURE 5: Comparison of modelled nitrogen content after Wessman et al. (left) and Dawson et al. (right) with verification data.

Spectral feature fitting results in similar correlation factors, but the distribution of the values is wider. Analysis of the spectral feature of chlorophyll is less successful than investigations in the short wave infrared region (Figure 6). It is possible, that the concentration of chlorophyll does not change significantly with a variation of nitrogen content ranging from 1.75 to 3.96%.

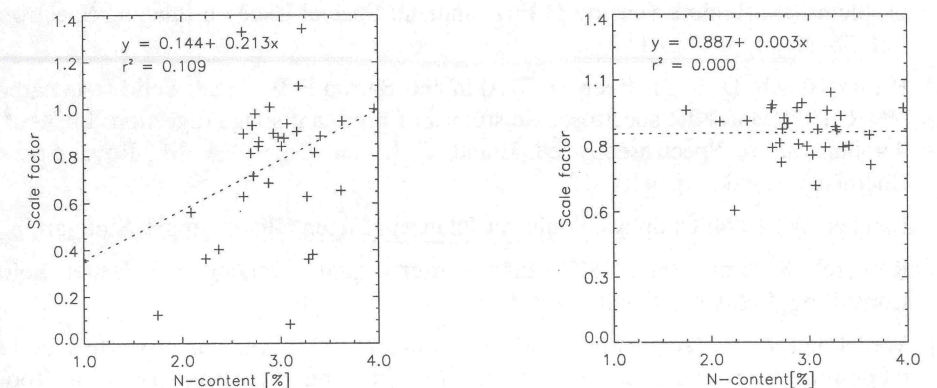


FIGURE 6: Correlation of the scale factor out of feature fitting with nitrogen content measured in the laboratory. The scale factor out of analysis over 1537-1585nm (left) show slightly better correlation than the feature fitting over the region of 545-770nm (right).

Neither correlation using values in significant wavelengths of derived spectra nor spectral feature fitting shows satisfactory results (r^2 at a maximum of 10-20%). Possible reasons are the effect of leaf water on plant reflectance spectra which can mask or shift absorption features of biochemical constituents. A second problem is the poor availability of nitrogen content references and the low quantity of plant material that is used for the CHN-analysis.

3.3 Discussion

The results show clearly, that there is a great potential to determine parameters like vegetation cover or LAI by analysing contiguous reflectance spectra. Investigation of biochemical constituents is more complex and not as successful as biophysical parameters of vegetation canopies. Therefore it is important, that a reference dataset of sufficient quality and quantity is available to verify the modelled results. Although results of biochemical analysis are disappointing at the moment, further work has to be done in this context, such as investigating the spatial distribution (N/m^2 and not $N\%$) because these parameters are an important input to the upscaling processes from single measurements to ecosystem levels at regional and global scale.

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TOPIC 6 :

LAND COVER MONITORING